

Empirical Analysis of Energy Consumption of Acceleration-Based Wireless Sensor Nodes Used for Pipeline Monitoring

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ABSTRACT: Energy Consumption is one the major constraint in developing Wireless Sensor Network (WSN) applications. An application can take years to drain the battery of the sensor node or consume it in a matter of weeks. Consequently, many authors have proposed different techniques of analysing energy consumption in sensor nodes with preference to energy consumed in communicating information within the network. This paper presents the empirical analysis of energy consumption of acceleration-based sensor nodes used for pipeline monitoring. We considered energy dissipated in sensing, controlling and communicating data at different operating states. The Lifetime of the network and energy dissipated by the sensor nodes were estimated per unit bit and for active, idle listening and sleep mode for the accelerometer, microcontroller and transceiver units respectively. The graphs of energy consumed at different packet size and Node Voltage with Lifetime were analysed using Matlab Simulation.

KEYWORDS: WSN, Energy Consumption, Acceleration-based Sensor nodes, Lifetime.

I. INTRODUCTION

Wireless Sensor Network (WSN) has been widely considered as one of the most important areas of research in the twenty-first century. The critical issue in developing WSN applications is the limited amount of energy usually available in the sensor nodes. An application can take years to drain the battery of the sensor node or consume it in a matter of weeks. Therefore, application developers must always adopt best practices in order to reduce the energy consumption of sensor nodes as much as possible [1]. Good knowledge of the sources of energy consumption in WSNs is the first step in energy consumption analysis. Therefore, an accurate energy consumption model is required for the evaluation of communication protocols [2]. The lifetime of sensor node is determined completely by the amount of energy available and the rate of energy consumption. Wireless Sensor Networks consist of a set of nodes capable of sensing, storing, processing, and communicating data from one node to another node. The functionality of a sensor node is generally implemented through four units which are sensing, processing, communicating and power units as shown in Fig.1. In order to increase the lifetime of the battery-based sensor nodes, it is essential to minimize the consumed energy in the process. Wireless sensor networks are widely used for real life applications such as environmental monitoring [3], agriculture [4], production and delivery [5], military [6], structural monitoring [7] and medical applications [8].

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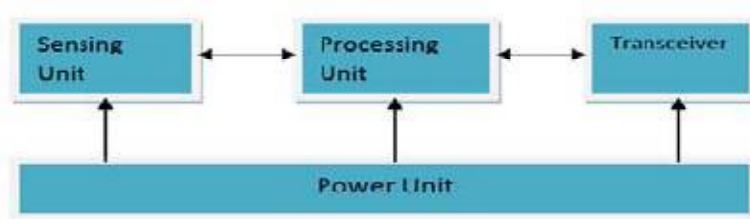


Figure 1: Components of a sensor node

II. RELATED WORK

Wireless sensor nodes' development represent a real challenge because of the numerous constraints associated with them. A wireless sensor node must incorporate a computing unit, power unit, a radio communication device and some sensors as shown in Fig. 1. In most cases, the energy constraints make an energy harvesting circuit necessary. In addition, everything must be assembled into a very small form factor device. Thus, the design effort is directed to the choice of low-power, small size devices. Since most of the WSNs paradigms require the nodes to wake up and perform some operations periodically, a key characteristic of all node's components is the stand-by power consumption, which has to be as low as possible. This is the reason why microcontrollers with a good power modes' management are largely preferred. The radio module choice is dictated by the application requirements, such as transmission range and data volume. Often, radio communication is done in high frequency (HF) bands, because of the benefits from the point of view of the antenna's size.

Nnebe in [9] present a statistical analysis of energy expended in transmitting and receiving of data in WSN using TelosB sensor nodes. The analysis only considered energy expended in communication which is just a unit of the sensor node. The authors in Stochastic Analysis of Energy Consumption in Wireless Sensor Networks also presents energy dissipated in communication [10]. They use Markov chain-based cross-layer analytical model to investigate the statistics of energy consumption in WSNs of instead of the average energy consumption. Polastre, Hill, and Culler in [11] proposed a model that presents the total energy consumption for Mica2 mote as the summation of energy in transmitting, receiving, listening, sampling data and sleeping. Values are calculated using the expected consumption of the CPU and the radio found in specific datasheets. It was specific for MicaZ motes.

III. METHODOLOGY AND SYSTEM DESIGN

The custom-built acceleration-based sensor nodes consist of KYL-500S Wireless Transceiver Module at ISM band frequency of 433MHz, operating on line-of-sight covering a distance of about 600m at 9600bps or about 1km at 1200bps. The processing unit uses a PIC18F2620 Microcontroller with operating frequency of 40MHz, 10-bit ADC and wide operating voltage from 2.0V to 5.5V. The sensing unit is a triple-axes accelerometer (MMA 7361) which can measure acceleration, vibration, and tilt in XYZ axes of any platform with a typical regulated voltage of 3.3V from 5V source. The whole unit is powered by a 9V alkaline battery regulated to 5V. Figs. 2 and 3 show the developed sensor node before packaging and after packaging with battery respectively.

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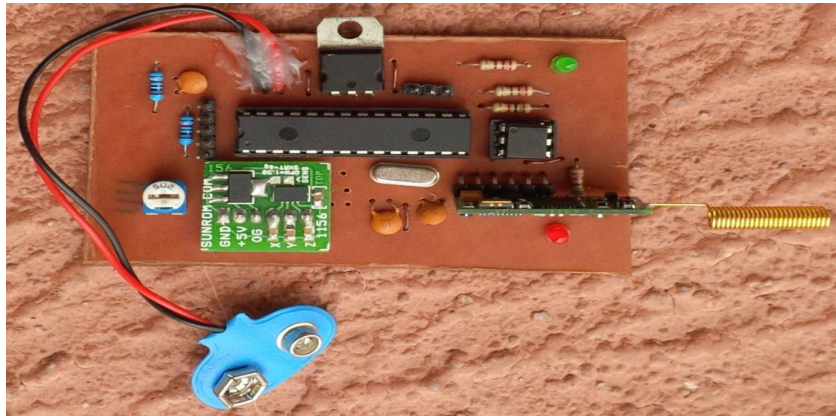


Figure 2: Developed Node before packaging



Figure 3: Developed Node after packaging with battery

The sum of energy dissipated by the individual nodes can be ascertained considering Table 1 with expected/typical current consumption of various component of the sensor node as extracted from the datasheets.

From Power Law;

$$Power(P) = Current(I) \times Voltage(V) \tag{1}$$

Table 1: Current and Power consumption of the Sensor Node

Element	Current(A)	Power(W)
PIC18F2620	Active mode 11μA	55μW
	Idle mode 2.5μA	12.5μW
	Sleep mode 100nA	0.5μW
KYL-500S Transceiver	Transmit 20mA	100mW
	Receive 10mA	50mW
	Idle mode 10mA	50mW
	Sleep 10μA	50μW
Vibration Sensor	Sensing 400μA	2mW
	Not sensing 3μA	15μW

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Table 2: Total power consumed by the node in each state

States	PIC18F2620	KLY-500S Radio (Tx/Rx)	Vibration Sensor	Total Power (W)
Active	55μW	100/50 Mw	2Mw	102.055/52.055mW
Idle	12.5 μW	50 Mw	–	50.0125mW
Sleep	0.5 μW	50 μW	15 μW	65.5μW
Total	68 μW	150.05/100.05 Mw	2.015mW	152.133/102.133mW

At transmission rate of 9600bps, the time to send or receive one bit = 1/9600bps = 104.167μsec.

Table 3: Total Node energy consumed per unit bit

States	Total power (mW)	Total energy (μJ/bit)
Active	102.055/52.055	10.63/5.42
Idle	50.0125	5.21
Sleep	0.0655	0.0068
Total	152.133/102.133	15.85/10.64

Measurement of Lifetime of a Network

In this paper, the lifetime of network is defined as the operational time of the network during which it is able to perform the dedicated task(s). One round is an operation that starts from the sensor node waking up to take measurement, sends data to sink node and the sink sends data to the base station. Since the sensor nodes are being powered by a 9V alkaline battery which is regulated to 5V, the battery Lifetime determines the network lifetime.

However, Lifetime (L) depends on the battery capacity (C) and load current (I) from the sensor node units. The capacity of most available 9V alkaline battery is between 500-600mAh [12]. The lifetime in hours could be calculated using the following relationship by Peukert law [13].

$$L = \frac{C}{I^n} \tag{2}$$

The Peukert's exponent n varies from 1 to 1.3 according to the age and type of the battery with 1 as the nominal value for most alkaline batteries [14].

A useful model for Lifetime can be derived by multiplying the numerator and denominator of (2) by supply voltage (V) with n = 1 for alkaline battery nominal value as:

$$L = \frac{C \times V}{P} \tag{3}$$

The lifetime (L) is given as: $L = \frac{600mAh \times 5V}{152.133mW} = 19.72hours$

IV. RESULTS AND DISCUSSIONS

Energy consumption is the amount of energy dissipated by the sensor nodes in sending data packets from one node to another node in the network. It is measured in Joule. From the analysis in Table 3, the energy consumed by the sensor nodes in sending data at different packet size is shown in Fig. 4. The Energy consumed was found to be proportional to the packet size since the network was assumed to be error-free. Network lifetime is the amount of time that a Wireless Sensor Network would be fully operative. One of the most used definitions of network lifetime is the time at which the first network node runs out of energy to send a packet, because to lose a node could mean that the network could lose

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some functionality. The Lifetime of the sensor node as time progresses with Voltage as measured is shown in Fig. 5. We observed that after 20 hrs, the voltage was at the minimum voltage of about 7.5V as estimated using the model.

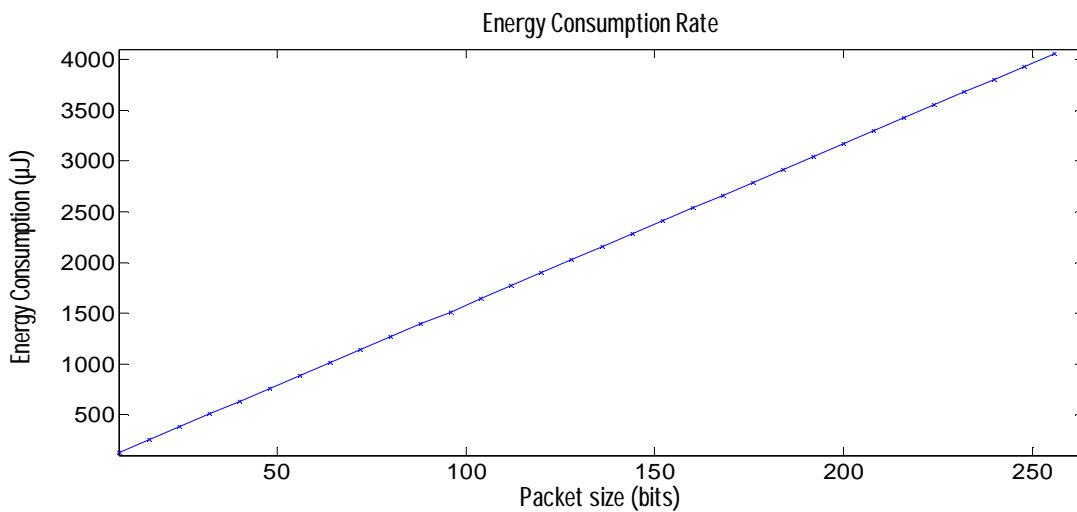


Figure 4: A plot of Energy dissipated at different packet size

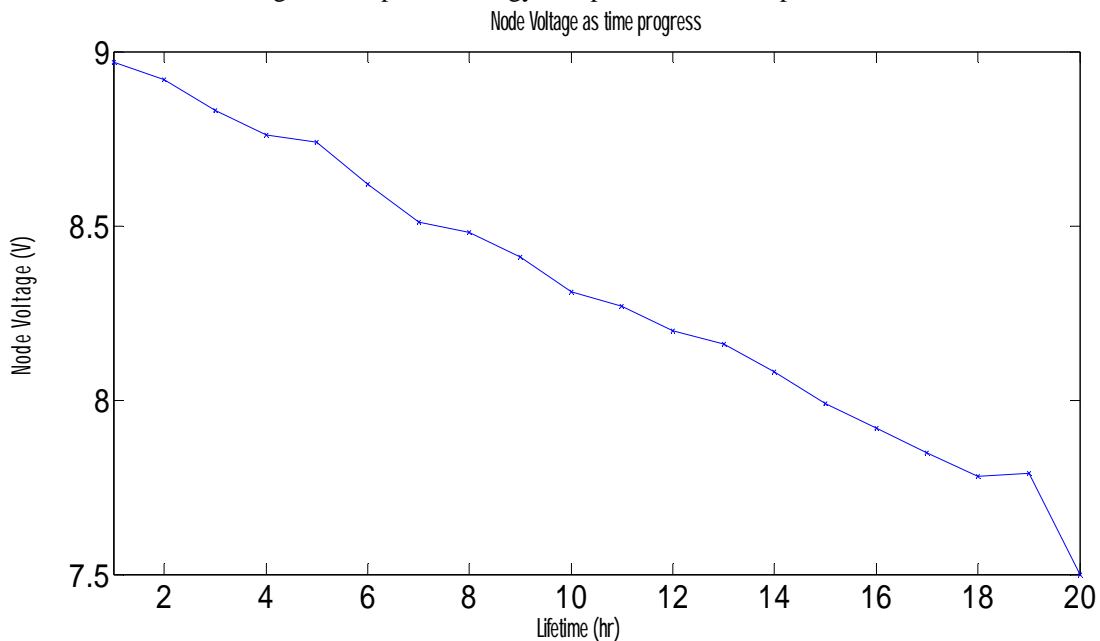


Figure 5: A graph of Node Voltage as time progresses

V. CONCLUSION

The primary limiting factor for the Lifetime of the sensor network is the energy supply. Each sensor node must be designed to utilize its battery in order to maximize total network lifetime. In this paper, an empirical analysis of the energy consumption of acceleration-based wireless sensor nodes was achieved. The energy consumed by the four (4)

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major component of the node instead of only the communication unit was measured and the lifetime estimated. The results of energy dissipated at different packet sizes and Lifetime of the sensor node were shown using MATLAB simulation. Future paper should incorporate energy management algorithms to reduce the energy consumption rate so as to maximize lifetime. Wireless charging is also another open research area that needs to be explored further for future works in the area of wireless sensor networks. Recently, wireless charging technology has been one of the emerging technologies in the field of electromechanical systems.

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